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⑥ COLOR EDGE DETECTION:
A COMPARATIVE STUDY

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ABSTRACT

A color edge may be measured by the max, mean, median or RMS (root mean square) of the intensity differences on the three color channels. The performance of these edge measures in various color coordinate systems is studied. It is observed that RMS gives the best performance in all the coordinate systems, followed by the mean, max and median in that order. Even in noisy images the RMS yields the smoothest edge output. Though the mean and max are of comparable performance, the max is more appropriate for the Y I Q and $K_1 K_2 K_3$ systems while the mean may be preferred to the max in the other systems.

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1. Introduction

There has been some recent interest in color edge detection [1-3]. In gray scale images, edges are defined as abrupt changes in brightness [4]. In color space, on the other hand, the image attribute is vector valued, consisting of three components, a common choice being the tristimulus values (red, green and blue components). There are other coordinate systems of color representation, such as the Y I Q system where Y corresponds to the luminance and I and Q jointly describe the hue and saturation, and the X Y Z, U V W and Lab coordinate systems. The components of these systems can be expressed as linear or nonlinear combinations of the basic tristimulus values R, B and G.

A color edge may be defined either as an abrupt change in the color (vector) space, or as a meaningful choice among the individual scalar edge responses of the three components. The detection performance using either of these approaches may vary from one coordinate system to another.

Nevatia [1] discusses a Hueckel-type edge detector in which edges are detected in the intensity, hue, saturation and chromaticity components independently; these are then linked based on certain directionality constraints. Though most of the prominent edges may be detected in the luminance component alone, he concludes that it is necessary to detect chromaticity edges in order to obtain connected edge segments in the resultant edge output.

Riseman and Arbib [2] describe edge mask techniques for

detecting edges in the intensity component, which they define as the mean of the three color components. They also describe a relaxation process for enhancing the prominent intensity edges.

Robinson [3] uses a mask technique to compute the edge output as the maximum among the 24 gradient values (for the three channels in the eight directions) and uses this to compare edge detection performance in the various coordinate systems. She concludes that the R G B space is not well suited for edge extraction. If one were to use all the three color components then their cross-correlation must be taken into account. On the other hand, if only the most prominent color component is to be used for edge detection, then G in R G B, Y in Y I Q, L in Lab, etc., may be appropriate choices; but this does not necessarily imply that edge activity is low in the other components.

In the next section we briefly discuss the fundamentals of color coordinate systems. In Section 3 we compare several methods of color edge detection and give illustrative examples. In the concluding section we summarize our results and observations.

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2. Color coordinate systems

We discuss here briefly the various color coordinate systems and their interrelations. For an excellent review of this topic see Pratt [5].

The RGB coordinate system

The simplest and most commonly used system for representing colors is the R G B coordinate system. (Commercially, color images are digitized in the N.T.S.C. receiver primary color coordinate system; we shall next describe a transmission color coordinate system). Each color is associated with a color vector in (R G B) space.

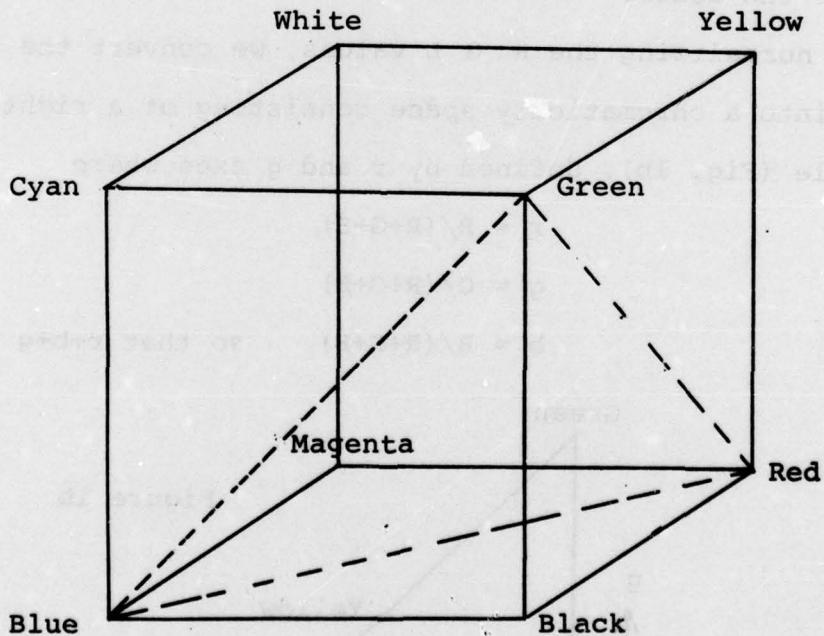


Figure 1a

The origin in the color cube (Fig. 1a) corresponds to black and the maximum brightness to white. The corners of the color cube are labelled with the names of the perceived colors which are formed by combining the three primary colors. The triangle which passes through the three primary colors is called the Maxwell triangle; the intersection point of a color vector with this triangle gives an indication of the hue and saturation of the color in terms of the distances of the point from the vertices of the triangle. Intuitively, hue is representative of the type of color while saturation measures the richness of the color.

By normalizing the R G B values, we convert the R G B space into a chromaticity space consisting of a right color triangle (Fig. 1b), defined by r and g axes where

$$r = R/(R+G+B)$$

$$g = G/(R+G+B)$$

$$b = B/(R+G+B) \quad \text{so that } r+b+g = 1$$

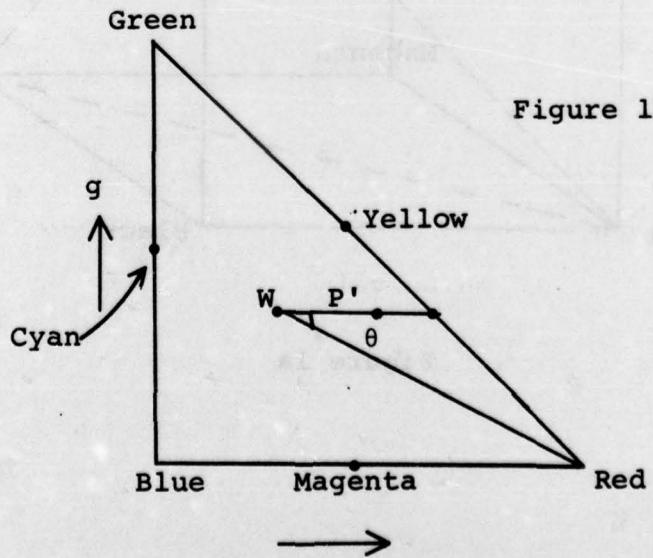


Figure 1b

The center W of the triangle corresponds to the projections of white and of all gray levels between black and white. The hue at a point P' is defined by θ where θ is the angle between the reference point and the extension of WP' onto the perimeter of the triangle. For instance, the hue of red is 0, that of green is 120, that of blue is 240, etc. The saturation at P' is the percentage of the distance of P' from W to the perimeter point H.

The Y I Q coordinate system

This is also known as the NTSC transmission color coordinate system. Since the Y signal alone can be used to display monochrome images and also I and Q can be band-limited without noticeable image degradation, the Y I Q system is preferred to the R G B system for transmission purposes. Y is a measure of the luminance of the color, while I and Q jointly describe its hue and saturation. The Y I Q system is related to the R G B space as follows:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.249 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The X Y Z coordinate system

This is also known as the C I E X Y Z color coordinate system. The Y tristimulus value corresponds to luminance.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.201 \\ 0.299 & 0.587 & 0.114 \\ 0.0 & 0.066 & 1.117 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The U V W coordinate system

This is also known as the C.I.E. uniform chromaticity scale color coordinate system. This system was developed to account for the fact that the human viewer is not equally sensitive to color shifts in the blue, green and red components, sensitivity being the greatest for blue and the least for green.

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} 0.405 & 0.116 & 0.133 \\ 0.299 & 0.587 & 0.114 \\ 0.145 & 0.827 & 0.627 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The L a b coordinate system

Here L is correlated with brightness, a with redness-greenness, and b with yellowness-blueness.

$$\begin{aligned} L &= 25 \left(100 \frac{Y}{Y_0} \right)^{1/3} - 16 \\ a &= 500 \left[\left(\frac{X}{X_0} \right)^{1/3} - \left(\frac{Y}{Y_0} \right)^{1/3} \right] \\ b &= 200 \left[\left(\frac{Y}{Y_0} \right)^{1/3} - \left(\frac{Z}{Z_0} \right)^{1/3} \right] \end{aligned}$$

where X_0 , Y_0 , Z_0 are the tristimulus values for reference white, viz. $X_0 = 0.982$, $Y_0 = 1.0$ and $Z_0 = 1.183$.

The Karhunen-Loëve coordinate system

This system is related to the R G B space through a linear orthogonal transformation based upon the covariance matrix of the three source tristimulus values:

$$\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \begin{bmatrix} 0.575 & 0.615 & 0.540 \\ 0.608 & 0.120 & -0.785 \\ 0.548 & -0.779 & 0.305 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

3. Color edge measures

Let the edge responses (obtained from any standard edge detection algorithm) in the three individual components be e_1 , e_2 and e_3 respectively. Then there are four possible ways of defining a color edge based on these components as follows:

- a) Max: $e = \text{Maximum } (e_1, e_2, e_3)$
- b) Mean: $e = (e_1 + e_2 + e_3) / 3$
- c) Median: $e = \text{Median } (e_1, e_2, e_3)$
- d) RMS: $e = \sqrt{e_1^2 + e_2^2 + e_3^2}$

See Table I for the expected responses of these measures for equal step edges in one, two and all three channels respectively.

An appropriate choice of the color edge measure depends on the choice of an edge model. For instance, if we assume that an edge response in only one channel is likely to be a noise response, the median method will obliterate such edges. On the other hand, if we assume that the strength of the color edge depends on the individual edge strengths in the three channels, then the maximum technique will fail to discriminate between edges of equal response in one, two and all three channels, respectively.

The max, mean, and median and RMS edge responses were computed for a set of images. The standard Roberts gradient algorithm was used to compute the edge responses in the individual channels. The following images were used:

Edge value			Max	Mean	Median	RMS
e_1	e_2	e_3				
h	0	0	h	$h/3$	0	h
h	h	0	h	$h/2$	h	$\sqrt{2}h$
h	h	h	h	h	h	$\sqrt{3}h$

Table I

- a) Real color images: Park, Room, Bear (Figs. 2-4)
- b) Noisy real images: Noisy Park, Room, and Bear images (Figs. 5-7). Gaussian noise with mean 0 and standard deviation 1 (on an intensity scale of 0-15) was added to each individual component.
- c) Synthetic noisy images

Fig. 8: Uncorrelated noise in each component, uniformly distributed over the interval $[0,15]$.

Fig. 9: Uncorrelated Gaussian noise in each component (mean 8, s.d. 2)

The color edge output of each of the four methods for every color coordinate system was normalized by transforming the range between the minimum and the maximum of the edge outputs into the closed interval $(0,1)$, so that the performance of the various methods could be compared. Hence it is not the brightness of the edge element that is important but rather the relative difference in strength between different edge elements as well as the smoothness of the edge output.

A careful inspection of Figures 2 to 7 reveals that the RMS method performs uniformly better in all the coordinate systems, followed by the mean, max and the median in that order.

Figure 2



Figure 3



Figure 4

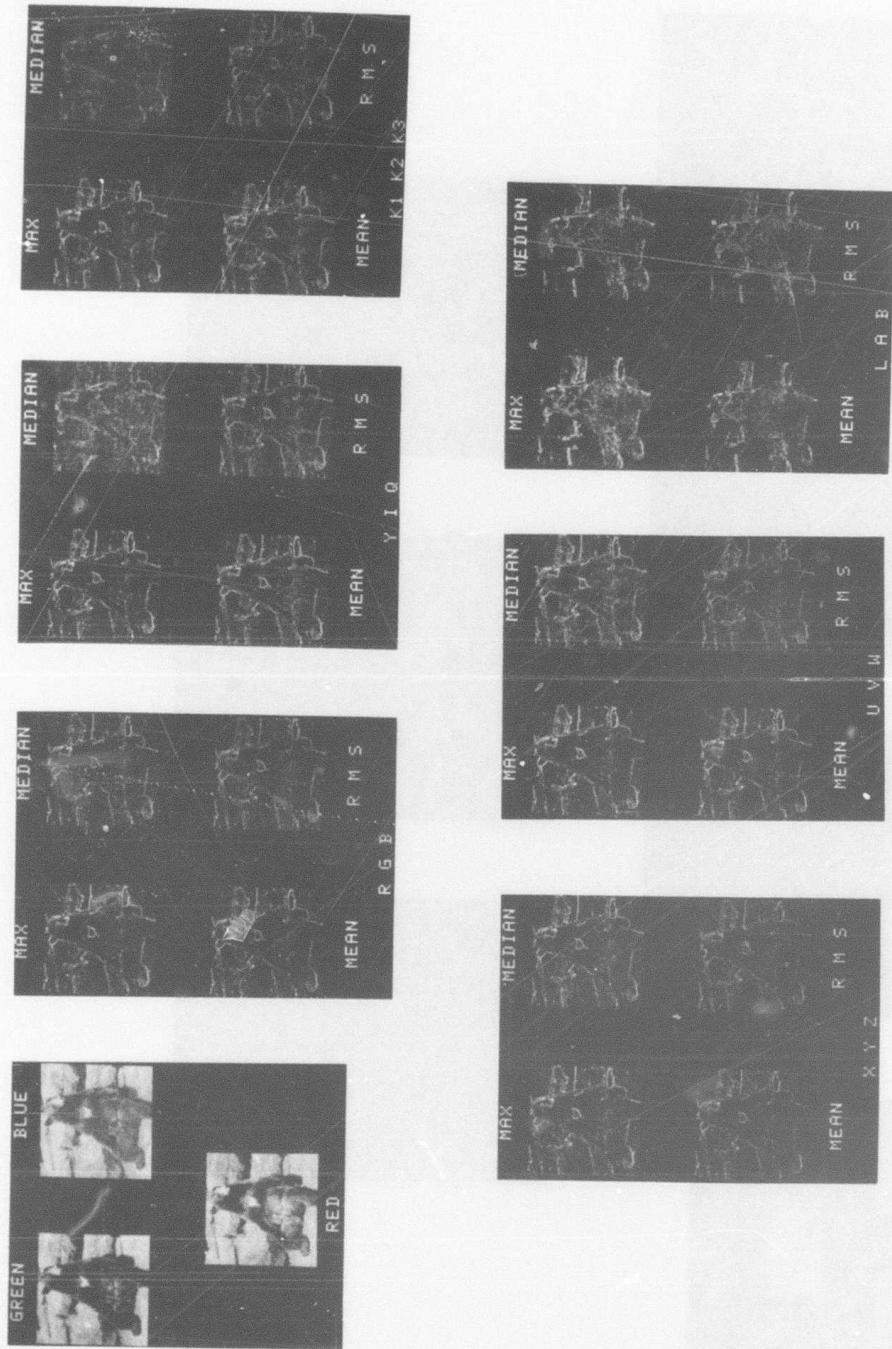


Figure 5

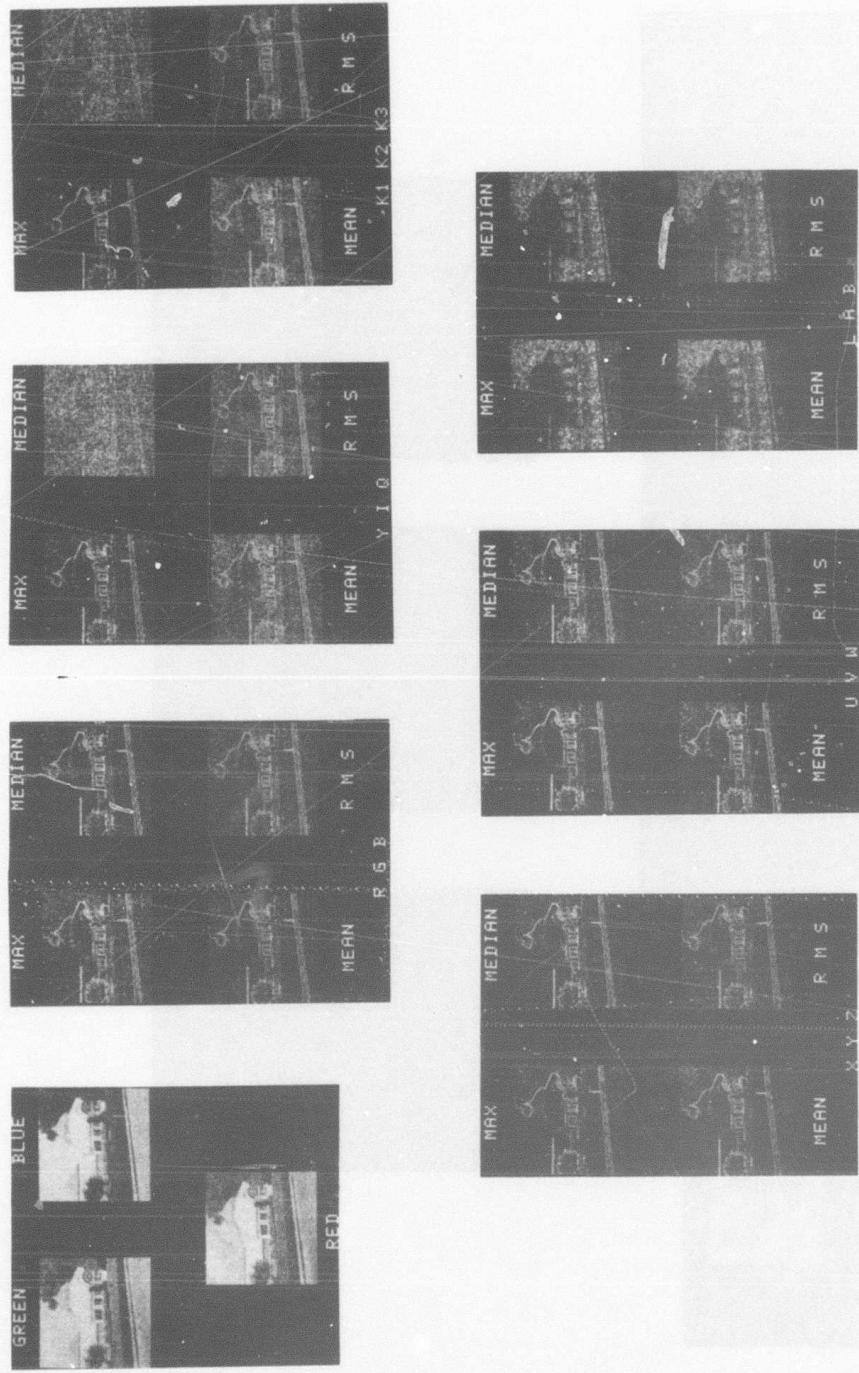


Figure 6

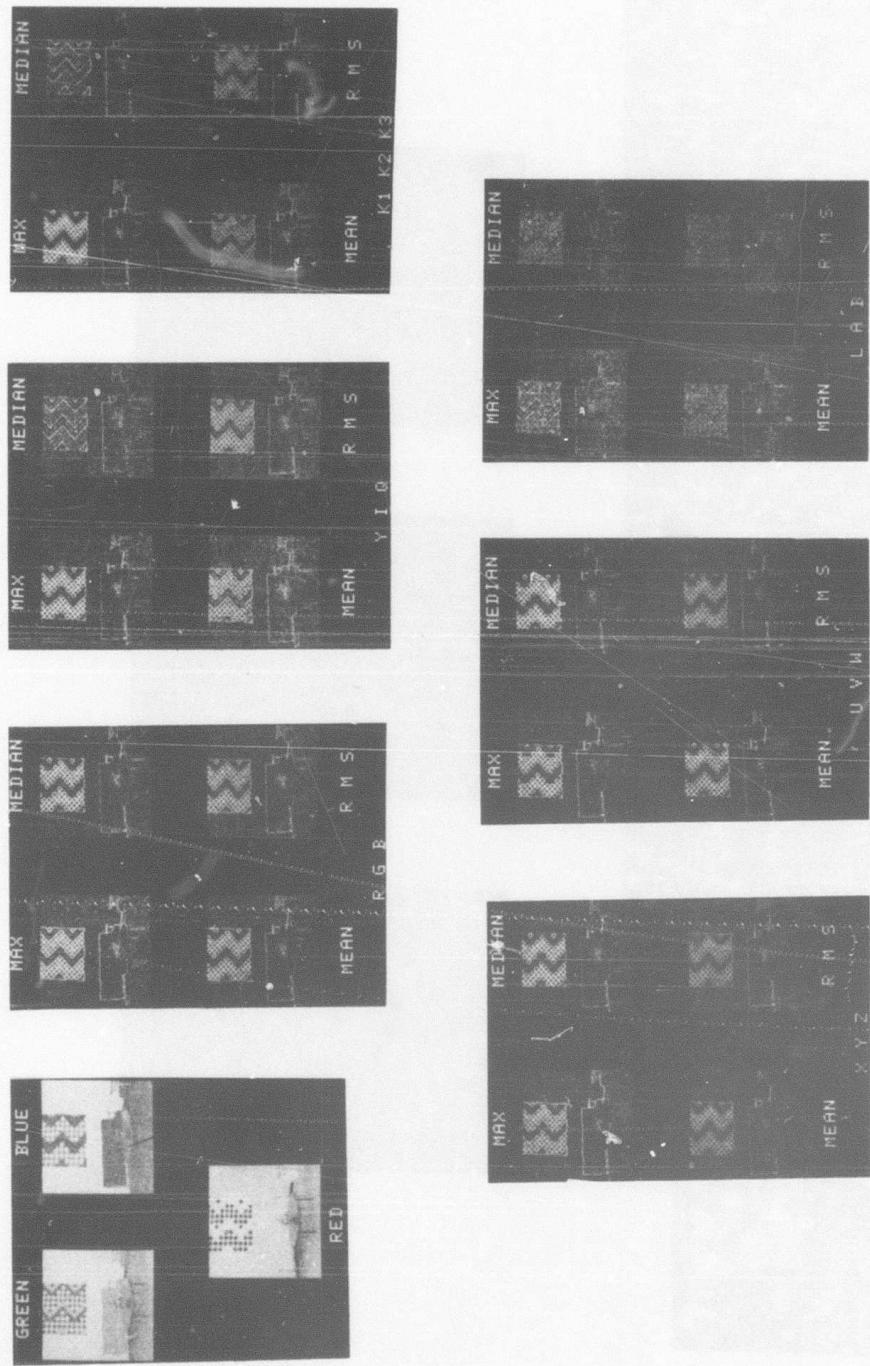


Figure 7

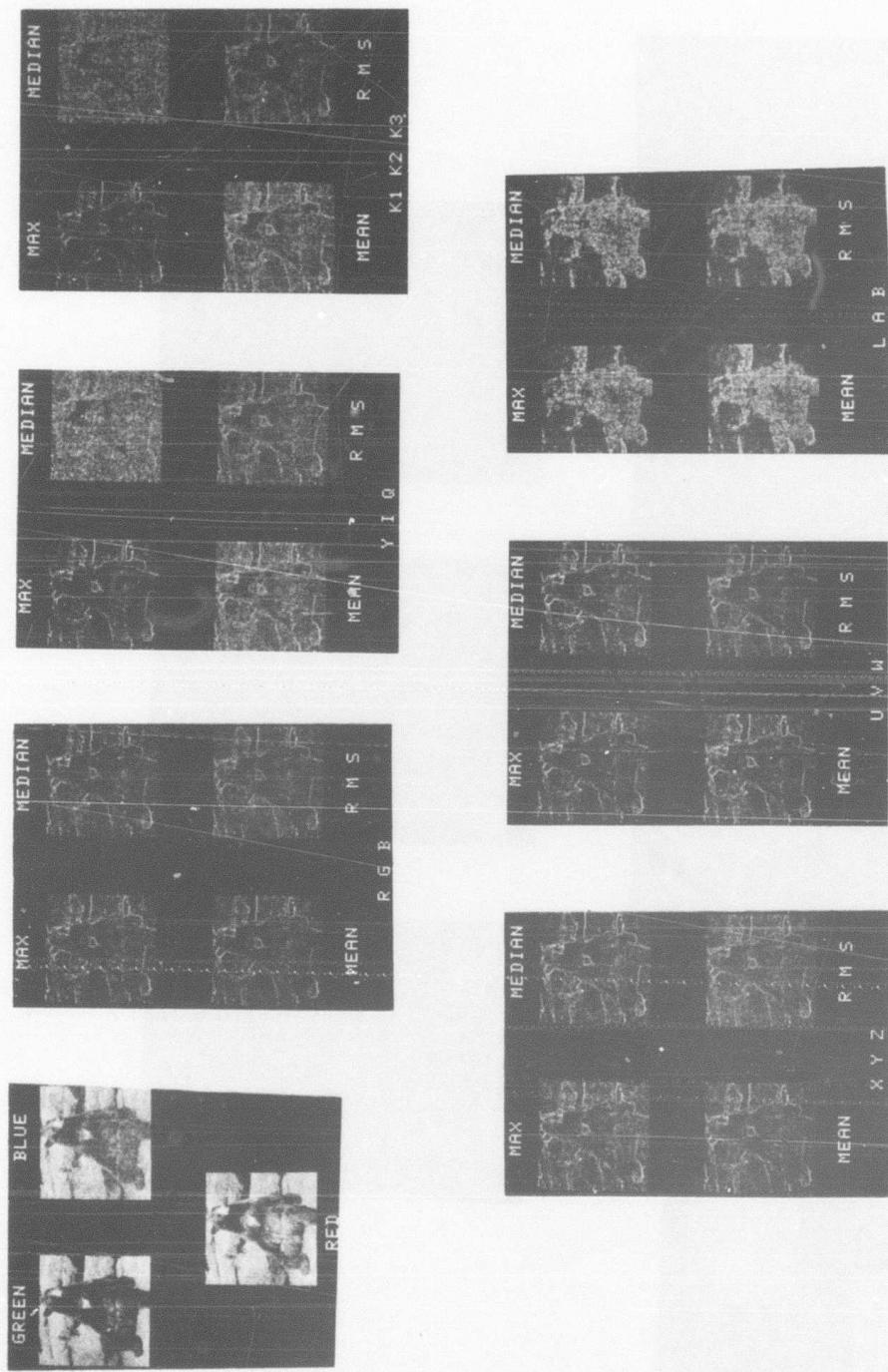


Figure 8

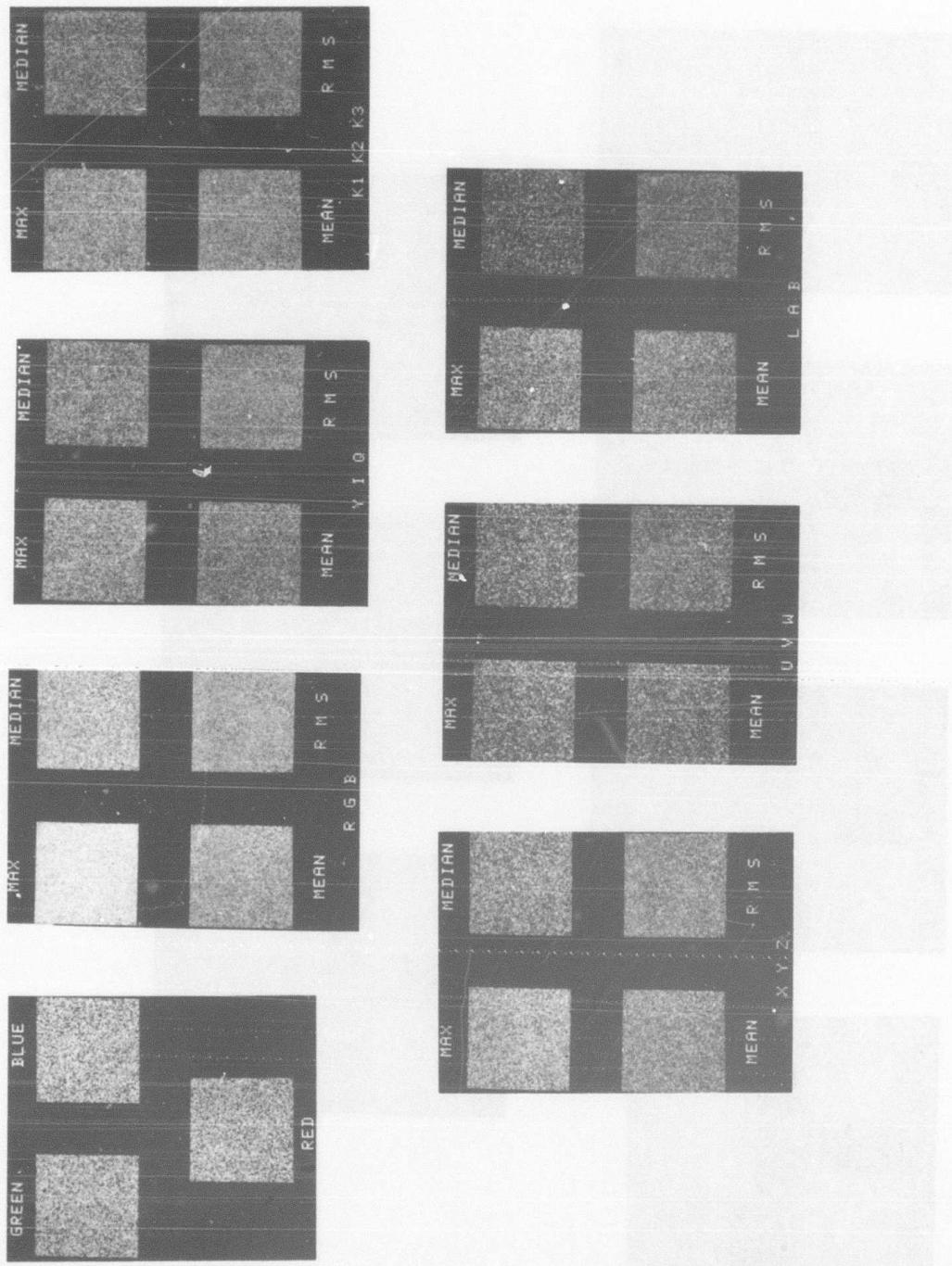
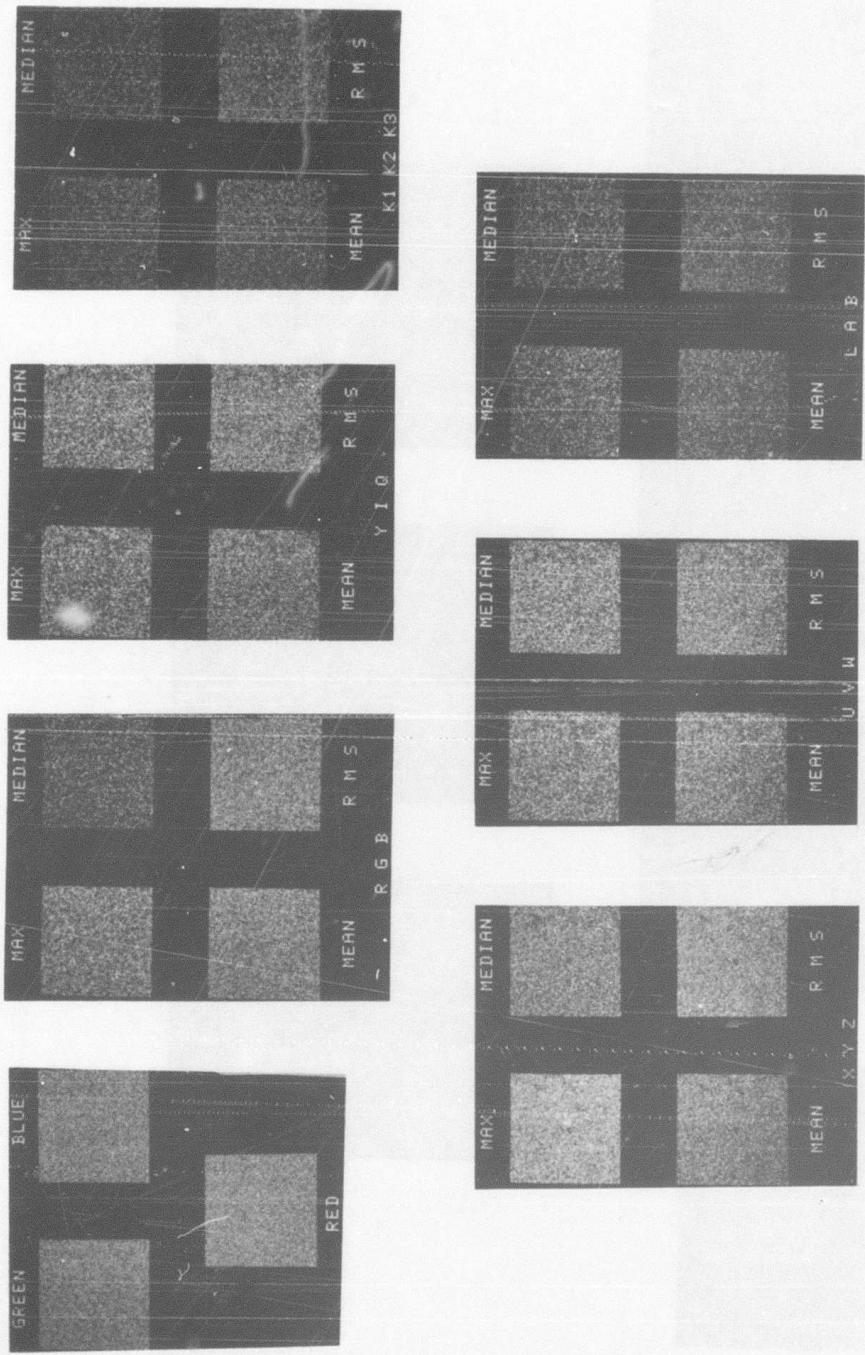


Figure 9



It is interesting to note that the RMS method detects not only all the significant edges (see the detection of the correct border of the cloud in the Park Scene, Fig. 2), but also gives the smoothest edge output even for noisy images (Figs. 5-7) and synthetic random color images (Figs. 8-9).

The mean and the max have competing performance; the mean performs better in the R G B, X Y Z, U V W and Lab coordinate systems, while the max does better in the Y I Q and $K_1 K_2 K_3$ systems.

The median performs poorly in the Y I Q, $K_1 K_2 K_3$ and R G B systems. (Note especially its effects on the picture on the wall in the Room Scene of Fig. 3). However, it does much better in the X Y Z, U V W and Lab coordinate systems.

Of all the coordinate systems, the Lab system seems to be very sensitive to noise (e.g., in the detection of textured edges in Figs. 2-7).

4. Conclusions

To summarize:

- a) The RMS method seems to be the best edge detector in all the coordinate systems, even for noisy images.
- b) The mean and the max have comparable performance; the mean is more appropriate for the R G B, U V W, X Y Z and Lab systems, while the max may be preferred in the Y I Q and $K_1 K_2 K_3$ systems. Also, the mean generally gives a smoother edge output than the max.

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